



LIGHTWEIGHT HIGH STRENGTH CONCRETE WITH EXPANDED POLYSTYRENE BEADS

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Abstract

This paper is a literature study about lightweight high strength concrete by incorporating expanded polystyrene beads. Basically polystyrene is disposal material from packaging industry. However, after being processed in a special manner, polystyrene can be expanded and used as lightweight concrete making material. Therefore, the use of expanded polystyrene beads in concrete is not only beneficial for engineering studies but also provide solution for the environmental problem.

Keyword: concrete, polystyrene beads

1. General Introduction

1.1 Expanded polystyrene (EPS)

Expanded polystyrene (EPS) is a lightweight cellular plastics material consisting of fine spherical shaped particles which are comprised of about 98% air and 2% polystyrene. It has a closed cell structure and cannot absorb water. Therefore, it has a good sound and thermal insulation characteristics as well as impact resistance (Cook, D.J., 1983).

EPS is an inert material which is quite resistant to alkalis, methanol, ethanol silicone oils, halide acids, oxidizing and reducing agents. However, it has limited resistance to paraffin oil, vegetable oils, diesel fuel and Vaseline, which can attack the polystyrene foam after long term contact.

Polystyrene foam is a non biodegradable material. It is a waste material from packaging industry. It may create disposal problem. Utilizing crushed polystyrene granules in concrete is a valuable waste disposal method. However, because it is a chemical material, there are contradict arguments appear in relation to its toxicity.

Polystyrene foams undergo deterioration slightly of their mechanical properties when temperature is increased to its 'glass transition temperature' (T_g) which is ranging from 71 °C to 77 °C (Ravindrarajah, R.S., & Tuck, A.J., 1993). Nevertheless, according to National Bureau of Standard Combustion Tests the level of toxicity of EPS when it is burnt is no greater than those from wood; similar toxic gas, carbon monoxide and carbon dioxide are produced.

However, when exposed to sunlight, the polystyrene beads will deteriorate and turn into yellow in color which is an indication of polymer degradation, although it may takes years. Nevertheless, this effect is unlikely happen when the beads are embedded in concrete (Cook, D.J., 1983).

addition, EPS is not containing chlorofluorocarbon (CFC) and Hydro chlorofluorocarbon (HCFC) (Chen, B. & Liu, J., 2003). Therefore, lightweight concrete with polystyrene beads is safe for the environment and is not contribute to the destruction of earth's ozone layer. Moreover, because polystyrene polymer has no nutritive value, it is not trigger fungus or any other bacteria growth and has no dangerous effect on plants or animals.

1.2 Production techniques of expanded polystyrene beads

Unexpanded polystyrene beads' sizes usually range from 0.25 to 2.5 mm in diameter and dry density from 550 to 800 kg/m³ (Cook, D.J., 1983). For use in concrete, the polystyrene beads have to be expanded.

The expanded polystyrene foam is produced using a chemical process called 'Chain polymerization'. Styrene monomer which made from benzene and ethylene is converted to linear polymer polystyrene in this process. During polymerization process, the double covalent bond between the carbon atoms is broken and redistributed to the end of the monomer to allow another styrene monomer to join. This process is

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continued until a long chain molecule is formed (Ravindrarajah, R.S., & Tuck, A.J., 1993).

The main types of construction of polystyrene foams are: moulding bead foam and extrusion. The moulding bead foam type is produced from expandable polystyrene beads by using a blowing agent, such as halocarbons, hydrocarbons and/or mixtures of both.

The polystyrene beads are converted to foam by heating them with hot water, hot air, or steam to yield pre-expanded beads. Then, the pre-expanded beads are subjected to heat again to reach additional expansion, flow to fill the spaces between fuse and particles. Basically, pre-expanded polystyrene beads are placed in a mould and steaming the particles to accomplish the expansion process and a good bead-to-bead consolidation is achieved.

In the construction of extruded polystyrene foam production, molten polystyrene is extruded at a particular range of temperature and pressure to a fissure orifice to the atmospheric pressure. The mass expands by 40 times its pre-extrusion volume in this condition (Ravindrarajah, R.S., & Tuck, A.J., 1993).

The diameter also can increase up to 6 mm while a more common size is 1 to 3 mm. In addition, extruded foam has a simple, more regular structure than moulded bead foam, as well as a better strength properties and higher water resistance.



Figure: Expanded Polystyrene Beads sample

1.3 History of lightweight concrete

The idea of lightweight concrete has begun from Roman times in the year 273 BC. The Roman engineers used volcanic tuff-porous volcanic rocks and fired clay. Later, during World Wars I and II lightweight high strength concrete ships were successfully used. The American Emergency Fleet

Corporation built lightweight concrete ships with specified compressive strength of 35 MPa, when the strength of commercial normal weight concrete at that time was 14 MPa (Shah, S.P. and Ahmad, S.H., 1994).

The volcanic aggregates are still being used for structural concrete in volcanic regions where there are ample supplies of natural lightweight aggregates, (Germany, Japan, and Italy). These aggregates enable to produce moderate strength concrete that has high thermal and fire resisting properties as well as good strength to weight ratios.

However, gaining higher performance with this material unfortunately may not be possible because of the inherent variability of the natural deposits in relation to the degree of expansion and non uniform vesicular diameter. These variations in quality limit its use, besides they are not available in many developed countries. Hence, research for manufacturing light aggregate was commenced in the nineteenth century (Newman, J. & Choo, B.S., 2003).

2. High strength concrete

Definition of high strength concrete is relative, depends on a period of time and location. For example in North American practice, high strength concrete is generally considered as a concrete with a 28-day compressive strength at least (42 MPa) in 1960s.

On the other hand, in the past (in 1950s), concrete with 35 MPa has regarded as high strength concrete. Recently, generally high strength concrete is defined as concrete with a minimum 28-day compressive strength of 60 MPa, although concrete with compressive strength excess of (70 MPa) can be achieved (Portland cement Association, 1994).

In the early 1970s, experts predicted that the practical limit would not exceed a compressive strength more than 76 MPa. However, over the past 20 years, the development of high strength concrete could achieve a concrete with compressive strength 131 MPa of two buildings in Seattle, Washington (Howard, N.L., and Leatham, D.M.,). It is a *very high strength* concrete as The American Concrete Institute defines *high strength concrete* as concrete with compressive strength more than 41 MPa, while a medium strength concrete (conventional concrete) is concrete in the range of 21-41 MPa

3. Reasons for using lightweight high strength concrete

The density of concrete can be reduced in many ways, such as by incorporating lightweight

aggregates, cellular foams, high air contents, and eliminating fine aggregate. However, only high quality lightweight aggregates can be used to improve the strength lightweight aggregate concrete (Shah, S.P. and Ahmad, S.H, 1994). Moreover, there are few reasons for using lightweight aggregates in concrete.

Firstly, it can reduce internal stress concentrations in the concrete which in turn leads to reduction of microcracks at low stress levels. This can delay the damaging effects caused by cyclic loading, thus enhancing the performance. It leads to conclusion that under similar test conditions the fatigue behavior of high strength lightweight concrete is comparable or somewhat better than high strength normal weight concrete.

Secondly, reduction of concrete density, by using lightweight aggregate is very important as cost savings in transporting and handling precast units on site can be achieved. Where the need of precast concrete is largely required the quality and performance of this architectural material are improved. In addition, rationalization and systematization could be carried out.

On the other hand, a normal precast concrete is difficult to transport from a factory to a building site due to highway weight restrictions. These restrictions limit the number of units that can be placed on each shipment, even if more space is available on the truck or trailer. This drawback becomes bigger as structures become larger.

Another reason for considering lightweight aggregates concrete is that sometimes the dead load of a normal concrete is near or above the capacity of the cranes used at a plant or at jobsite. By using lightweight aggregates, it could be possible to reduce the weight of the product so that the high capacity cranes would not be necessary, or to produce larger sections than would not be possible with normal-weight concrete.

With reduced density, lightweight concrete will have a correspondingly reduced formwork pressure, which is very useful when casting deep sections. Yet, water that has been absorbed into the pores of the lightweight aggregate (except in polystyrene beads) will be available for curing.

The obvious benefit of using lightweight concrete for construction is that a reduction in dead loads causes cost savings in foundations and reinforcements. Thus, reduction in weight can lead to improved economy of structural components because there will be less dead load for the structure elements to support.

In the contrary, according to Cook (1983), the economic viability of a building component is not the only function of cost-benefits of the materials from which it is made, but also the availability of alternate materials and the method of manufacture.

In some countries, where expanded polystyrene for concrete are not produced and other lightweight aggregate supplies are available, the use of polystyrene beads for concrete are not economical. However, in some situations that is not the only case.

For example in West Germany, a study conducted by Seichler and Taprogge (Cook, D.J., 1983) shows that rendering expanded polystyrene concrete had much more cost-benefit than rendering aerated and expanded clay concrete in non-load bearing panels.

On the other hand, the reduction of cost in building concrete structures can also due to drastic reduction in member size, especially in columns. In fact, in concrete columns, high-strength concrete can hold more weight and therefore can allow more useable space, especially floors of buildings.

Some people consider that concrete is ugly, hard, cold, and difficult to work with. However, it is not absolutely right. There are a whole range of lightweight concrete with density and compressive strength comparable to those for wood (reddiform.com, 2004).

In the future lightweight concrete can be nailed with ordinary nails without cracks, can be sawed, drilled with woodworking tools, and easily repaired. Therefore, various-long term researches regarding lightweight concrete are being conducted to produce the ultra-light weight concrete.

4. Applications of lightweight concrete

Lightweight structural concrete is used in construction because its lightweight with high strength properties. Particular types of structures such as shells and roofs can be built efficiently with lightweight strong concrete.

There are various type of aggregates can be used to produce lightweight concrete, such as expanded shales, polystyrene beads, clays, slates, slag, and pumice or scoria, which are naturally occurring volcanic aggregates. Basically the material used depends on availability of lightweight materials.

In San Miguel, for example, a type of pumice (*espumilla orarenilla*) which is locally available was used to make lightweight concrete for

walls and roofs. Lightweight concrete having a good resistance to heat and sound was used as soundproofing material in subway stations (Shah, S.P. and Ahmad, S.H., 1994).

In Germany, 'no-fines concrete' was used. In this concrete, the aggregate cord-holes are covered with a thin cement paste layer and thus are bonded together at point-to-point cement contacts (Short, A. & Kinniburgh, W., 1978). Approximately 15% of the wall building block production in Germany is made from no-fines lightweight concrete.

In Hong Kong, four types of lightweight concrete (LWC) are commonly used. They are autoclave aerated concrete (plus lime), autoclave aerated concrete (plus fly ash), concrete with synthetic aggregate 'Leca' (light expanded clay aggregate) and concrete with polystyrene beads. Lightweight concrete was introduced in Hong Kong for partition walls in public housing. Recently, lightweight concrete has a wide range of applications. However, in Hong Kong it is mostly limited to the use in non-load bearing partition walls (reddiform.com, 2004).

In Armenia, being in an earthquake region, Armenian engineers learned early the advantages of reducing the density of the concrete in order to reduce the mass of the structure and thereby can reduce lateral forces. The advantages of High Performance Lightweight Concrete also have demonstrated for offshore platforms, which are currently used in Japan, USA, UK, Canada, Norway, and Australia (Malhotra, V.M., 1995).

In New South Wales and Queensland, in Australia, lightweight concrete is used as a sound barrier. Concrete panels are used as a noise abatement system to reduce traffic and pavement noise originating from freeways. This 10 km freestanding reflective noise wall is made from 4000 x 600 mm² panels, which are stacked horizontally to varying acoustic design heights (hebelaustralia.com, 2004).

5. Application of polystyrene beads in concrete

Despite its most application in packaging industry (Ravindrarajah, R.S., & Tuck, A.J., 1993), polystyrene beads are lightweight material which can be incorporate with concrete mixture to make lightweight concrete. However, polystyrene beads have its drawbacks when incorporating in concrete mixture: (a) it is very light which can cause segregation in mixing, and (b) its hydrophobic (difficult to wet when mixing) characteristic, so chemical treatment on its surface is needed. Hence,

it is low in strength, poor in workability and slump (in the fresh concrete state).

Therefore, generally it is used in combination with other materials like steel (to make sandwich panels) which usually used for cold store construction, as the expanded polystyrene is good as a thermal insulation. Due to its good energy absorbing characteristics, polystyrene concrete can also be used as a protective layer of a structure for impact resistance.

According to Cook (1983), principally, expanded polystyrene concrete is used for prefabricated non-load bearing panels, hollow and solid block, lightweight sandwich panels and in highway construction as part of the sub-base where frost is harmful for sub grade stability.

In building and construction, expanded polystyrene concrete almost can be used in any application where a combination of insulation and strength are required, such as roofs, cladding panels, curtain walls, ceiling, load-bearing concrete blocks, floating marine structures and sub-floor systems.

In Australia, the primary use of polystyrene aggregate concrete has been the manufacture of non-structural components of concrete buildings including perimeter insulation, roof insulation, and masonry insulation. The structural use of is of much interest to engineers since it is envisaged that structural members made with polystyrene aggregate concrete would have certain advantages over those made weight normal weight concrete (Lai, K.L., Ravindrarajah, R.S., Pasalich, W. and Hall, B., 1996), such as:

- (a) The lighter weight precast polystyrene aggregate concrete members would be easier to handle
- (b) The formwork would need to withstand a lower pressure
- (c) The size of the foundation can be reduced
- (d) The lower thermal conductivity of polystyrene aggregate concrete would improve the fire rating of the building
- (e) The better energy-absorbing capacity of polystyrene aggregate concrete would be beneficial in structures which are likely to be subject to dynamic or impact loading such as buildings in earthquake zones and buildings which store explosives.

At the University of Technology, Sydney, significant research has been done in the development and properties of polystyrene aggregate concrete containing expanded polystyrene beads as well as waste polystyrene

granules for over ten years and findings were reported elsewhere (Ravindrarajah, R.S., Difalco, V., and Surian, S., 2005).

6. Superplasticiser

Inevitably, the use of expanded polystyrene beads needs reducer agent (for instance: superplasticiser) in order to reduce its drawbacks in concrete especially in the fresh state.

According to Troy (Troy, J.F., 1982), there are two reasons to use superplasticiser in concrete: firstly to increase workability, that way concrete flow and self-compacting and self-leveling. For example a concrete mix has a slump 75 mm. When superplasticiser is added to this mix, the slump will excess 200 mm. As a result, a concrete contain a superplasticiser requires very little compaction.

Secondly, water content can be reduced by using superplasticiser in order to achieve high strength concrete. A normal water reducer only reduce water content about 10%, while superplasticiser can reduce water content as much as 30%, as well as maintain the workability. Consequently, a higher early strength of concrete is achieved due to large reduction of water content.

According to Biagini (Paillère, A.M., 1995), high-range water reducers (superplasticiser) affect different properties of concrete at different states, they are: in fresh state, setting state, and hardened state.

In fresh state, the application of high-range water reducer can affect: increase unit weight of concrete, increase the ability of concrete to flow, improve the cohesion as a consequences of the reduction of water in concrete, slightly increase air content, enhance slump loss of concrete, improve pumpability of concrete, but decrease segregation of concrete.

In the setting state, on the other hand, the use of high-range water reducer does not give significant retardation, but does increase plastic shrinkage cracking if evaporation was high, while bleeding is reduced by the use of high-range water reducer (Paillère, A.M., 1995).

In hardened state, the strength of concrete is increased considerably by the use of water reducer as a consequence of the reduction of water to cement ratio, capillary absorption and permeability of concrete are reduced, and the drying shrinkage of concrete is reduced mainly because of the reduction of water content in concrete.

7. Applications of lightweight high strength concrete

In North America, high strength lightweight concrete with compressive strength ranging from 35 to 55 MPa has been used satisfactorily about forty years by North American precast and prestressed concrete producers (Shah, S.P. and Ahmad, S.H., 1994).

In Australia, the use of high strength concrete in buildings, such as: Melbourne Central-70 MPa at 56 days, The Rialto Project and Shell house – both are 60 MPa at 56 days, and a building at 135, King Street, Sydney - 60 MPa at 56 days (Mak, S.L., Darvall, P.L.P., and Attard, M.M., 1989).

In Asia, Japan for example, high strength in concrete has been used for producing prestressed concrete (PC) girders of bridges to reduce dead load and to achieve longer span with compressive strength above 49 MPa required by Japanese Industrial Standard (JIS) (Shah, S.P. and Ahmad, S.H., 1994). The examples of these bridges are: Dai-ni-Ayaragigawa Bridge, Ootanabe Bridge, Iwahana Bridge, Kazuki Bridge, and Akkagawa Bridge.

In Indonesia on the other hand, type of concrete that generally used is conventional concrete while high strength concrete is not commonly used because of earthquake and non-cost effective. The use of high strength concrete has been limited to the metropolitan areas, such as Jakarta and Surabaya which is applied in high-rise buildings. Therefore, the use of lightweight aggregate such as polystyrene beads utilized in high strength concrete would be very useful as polystyrene aggregate concrete has better energy-absorbing capacity which would be beneficial in structures which are likely to be subject to earthquake.

In Norway, high strength concrete has been utilized for offshore exploitation of petroleum resources in the North Sea since 1973 (Rønneberg, H. and Sandvik, M.). The reason why lightweight high strength concrete is needed in the marine structures because many offshore concrete structures are constructed in shipyards which is located in lower latitudes and then floated and towed to the project site, therefore there is special needs to reduce weight and enhance the structural efficiency of cast-in-place structure (Shah, S.P. and Ahmad, S.H., 1994). In addition, concretes with compressive strength more than 42 MPa have been used in offshore structures since the 1970s.

In terms of concrete mixes, there is an indefinite method of mix proportioning of concrete. Mix designs for high strength concrete, until now, have been developed empirically, depends on the raw material available in any locations. As the increasing demands of longer spans, smaller section sizes, and larger and taller structures, the demands of high strength concrete also increase because of its structural advantages.

In economic aspect, the use of high strength concrete also contribute obvious short term and long term advantages, as the high strength concrete can achieve high strength at early ages and also can reduce the maintenance cost at the long term period.

8. Advantages of using high-strength concrete

There are major advantages of using high-strength high-performance concrete which is often balance the huge material cost: (Nawy, E.G., 2001)

1. Construction of high-rise buildings will save the real estate costs, especially in congested areas.
2. Greater stiffness as a result of a higher modulus of elasticity. Therefore, for the same size concrete members, high strength concrete has a greater resistance to vertical and horizontal deformations (lateral drift).
3. Higher resistance to freezing and thawing, chemical attack, and remarkably improved long-term durability and crack propagation.
4. Lower creep and shrinkage.
5. Longer spans and fewer beams for the same magnitude of loading.
6. Reduction in member size, resulting in:
 - (i) increase space, especially of floor buildings and
 - (ii) reduction in the volume of produced concrete as well as saving in construction time.
- 7.Reduction in self weight and superimposed dead load as well as saving in smaller foundations.
- 8.Reduction in formwork area and cost accompanied by reduction in shoring and stripping time due to high early-age achieved in strength.
- 9.Reduced maintenance and repair costs; therefore
- 10.Smaller depreciation as a fixed asset.

In ACI compilation (Howard, N.L., and Leatham, D.M.), an example of high rise column, by specifying 14 MPa greater concrete strength, 20

#11 reinforcing bars can be eliminated with a net savings of US\$400 per column. Besides, by increasing the compressive strength of concrete from 34.5 MPa to 69 MPa, the cross sectional area of column is reduced by a half.

However, incorporating lightweight aggregate such as polystyrene beads in high strength concrete might be resulting different properties from normal weight high strength concrete. Experimental results by Sabaa and Ravindrarajah (1997) showed that creep and drying shrinkage of polystyrene aggregate concrete increased, while compressive strength and modulus of elasticity decreased with decrease in the density of concrete.

9. Conclusion

Expanded polystyrene beads are waste material from packaging industry that can create disposal problem. However, despite its disadvantages as chemical material, polystyrene beads can be used as lightweight concrete making material and environmentally save. Utilizing crushed polystyrene granules in concrete is a valuable waste disposal method.

Lightweight high strength concrete produced has applied in lots of countries around the world, mostly for non load bearing structures.

Significant researches are continuously done to improve the quality of lightweight high strength concrete with expanded polystyrene beads.

10. References

- Chen, B. & Liu, J. (2003), *Properties of lightweight expanded polystyrene concrete reinforced with steel fiber*.
- Cook, D.J. (1983), Chapter 2: *Expanded polystyrene concrete*, in the book of *Concrete Technology and Design vol.1, New Concrete Materials*, editor: Swamy, R.N., Surrey University Press, pp 41-68.
- Howard, N.L., and Leatham, D.M., *The Production and Delivery of High-Strength Concrete*, ACI-compilation 12-Concrete Mixtures, Detroit, Michigan, and pp.4-17.
- Lai, K.L., Ravindrarajah, R.S., Pasalich, W. and Hall, B.(1996), *Deformation Behaviour of Reinforced Polystyrene Concrete Beam*, ADCOMP'96, Second International Conference on Advances in Composites 1996, 18-20 December, 1996, Bangalore, India.

- Mak, S.L., Darvall, P.L.P. (1989), and Attard, M.M., *A Review of the Use of Silica Fume in Very High Strength Concretes*, Report 7/1989, Monash University, Australia,.
- Malhotra, V.M. (1995), *Advances in Concrete Technology*, Proceedings, second CANMET/ACI International Symposium, Las Vegas, Nevada, USA.
- Nawy, E.G. (2001), Chapter 10: *Fundamentals of High Performance Concrete*, 2nd edition. (No. 624.1834)
- Newman, J. & Choo, B.S. (2003), *Advanced Concrete Technology, Constituent Materials*.
- Paillère, A.M. (1995), *Application of Admixtures in Concrete*, Rilem Report 10, first edition, published by: E & FN Spon, an imprint of Chapman and Hall, London, UK.
- Portland cement Association (1994), *High-Strength Concrete*.
- Ravindrarajah, R.S., Difalco, V., and Surian, S. (2005), *Effect of binder material on the properties of lightweight polystyrene aggregate concrete*, The IV International ACI/CANMET Conference of Quality of Concrete Structures and Recent Advances in Concrete Materials and Testing, Goiania-Brazil, June 1-3, 2005.
- Ravindrarajah, R.S., & Tuck, A.J. (1993), *Lightweight concrete with expanded polystyrene beads*, Civil Engineering Monograph No. C.E. 93/1 M.E, Sydney, March 1993.
- Rønneberg, H. and Sandvik, M., *High Strength Concrete for North Sea platforms*, ACI-compilation 12-Concrete Mixtures, Detroit, Michigan, and pp.9.
- Sabaa, B. and Ravindrarajah, R.S. (1997), *Engineering Properties of Lightweight Concrete Containing Ccrushed Expanded Polystyrene Waste*, Materials Research Society, 1997 Fall Meeting, Symposium MM: Advances in Materials for Cementitious Composites, December 1-3, 1997, Boston, USA.
- Shah, S.P. and Ahmad, S.H. (1994), *High Performance Concrete: Properties and Applications*, published by: McGraw-Hill, Inc. Great Britain, 1994.
- Short, A. & Kinniburgh, W. (1978), *Lightweight concrete*, third edition, published by: Applied Science Publishers Ltd., London, pp. 6-23, 42-54, 64-90.
- Troy, J.F. (1982), *Ice works construction guides, Concrete materials technology*, published by: Thomas Telford Limited, London.
- www.hebelaustralia.com, 2004.
- www.reddiform.com, 2004.